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Determination of the Most Economic Concrete

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DETERMINATION

OF

THE MOST ECONOMIC CONCRETE

BY

BENJAMIN BENTON STAKEMILLER

THESIS

FOR THE DEGREE OF BACHELOR OF SCIENCE

IN CIVIL ENGINEERING

COLLEGE OF ENGINEERING

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Benjamin Benton Stakemiller

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OF Bachelor of Science in Civil Engineering.

Ira O. Baker.

HEAD OF DEPARTMENT OF Civil Engineering.

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Introduction.

Engineering literature contains a considerable amount of data on the strength of concrete; but there is nothing directly concerning the most economic concrete, and the little data there are is so meagre and so variable as to make it practically impossible to draw any conclusions therefrom concerning the economics of concrete.

The determination of the most economic concrete involves a consideration of the following factors: the relative merits of gravel and broken-stone, the hardness of the aggregate, the fineness and strength of the cement, the relative merits of natural and Portland cements, the proportion of the cement to the sand, and the proportion of the mortar to the aggregate.

The writer decided to make some experiments concerning the most economic concrete; but as the time available would not permit a thorough study of the whole

subject, he decided to limit his investigation to a determination of the most economic concrete of a given proportion, using gravel and broken-stone, and natural and Portland cements.

In proportioning concrete it is almost the universal custom to make the volume of the sand two or three times, and the aggregate four to six times, the volume of the cement, irrespective of the voids in either. In other words, the proportions are fixed independent of the conditions of the aggregate used. It is clear that the more nearly the voids of the aggregate are filled, the stronger and more dense will be the concrete. The writer therefore carefully determined the volume of the voids in the sand and the aggregate.

A concrete which would have considerable strength at an early date seemed preferable, and as previous experiments* showed that to fill the voids of the aggregate with mortar required that the latter should be considerably in excess of the former: the writer therefore

* Oakis' masonry Construction, p. 112 b.

decided to use a concrete in which the volume of the mortar was equal to 125 per cent of the volume of the voids in the aggregate. Only two cements were tested, as the time in which the experiments had to be completed was limited.

Materials.

The sand was secured from a drift sand east of Urbana. It was sharp, but was mixed with a small amount of clay which, of course, detracted from the quality of the resulting concrete. The gravel was also obtained from a pit east of Urbana and had considerable clay mixed with it. The broken-stone came from the limestone quarries at Kankakee, Illinois, and was broken to such fineness that it would pass a two-inch ring.

Table I shows the fineness of the sand.

Table I.

Fineness of the Sand.

Sieve Number	Per-Cent Caught on	Per Cent Passing.	Total	
			Per Cent Caught on.	Per Cent Passing.
20	39.70		39.74	60.26
30	16.90		56.64	43.36
50	17.42		74.06	25.94
75	20.18	5.60	94.24	5.60

The method of determining the volume of the voids was as follows: A known quantity of water was placed in a measuring can and the material slowly dropped into it and allowed to settle to the bottom, after which it was thoroughly tamped. By causing the material to pass through the water in small quantities, all the air is excluded from the voids and a more accurate result secured. When the material in the can has been raised to the same level as the water, the per cent of voids may be determined by dividing the volume of the water used by the total volume filled in the measuring can.

The per cent of voids in the sand determined by this process was 31.4 per cent. The per cent of voids in the gravel was 32.42 per cent, and in the broken-stone 40.0 per cent.

The cubes were made in gang molds, there being two to a gang. These were made from two-inch oak and were bolted together in such a manner that they could be removed from the cubes without

damaging them.

The apparatus used in making the concrete consisted of a mortar-box, trowel, and rammer. The rammer was cast-iron, 3" × 3" on the tamping face, about three feet in length and weighed about nine pounds.

The mortar-box was only large enough to hold concrete for two cubes and as four were required for each test, two batches of concrete had to be mixed. Some slight variation in the results arose naturally from this cause, as it is next to impossible to obtain the same mixing in one case as in the other. The two batches of concrete were made one right after the other so that the atmospheric conditions were practically the same.

In one or two instances the crushing strengths agreed very well two and two, but the mean of the pairs varied considerably. The only explanation I can give for this is the difference in the mixing, as the tamping in all cases was very nearly uniform.

The sand and cement were thoroughly mixed while dry, the per cent of the dry

cement to the sand equaling 125 per cent of the voids in the sand. Enough water was added to make a plastic mortar, after which the mass was again thoroughly mixed.

The aggregate was very dry having been kept indoors for sometime, and knowing that in such a state it would soak up the water and weaken the mortar, I dampened it before mixing the two. In the mixing care was taken that each separate piece should be thoroughly covered with mortar before moulding.

The concrete was tamped into the molds in layers of from two to three inches thick and care was exercised that it should be thoroughly and uniformly tamped.

After the molds had been filled the surface of the specimen was trowelled off smoothly in order that an even bearing should be secured in the testing machine.

The plasticity of the concrete was such that after thoroughly tamping, a thin film of water rose to the surface.

The concrete was kept in the molds for several days to allow it to become fully set, and during which time it was kept covered with damp clothes. It was then released from the molds and placed under water until the time for crushing.

The thirty- and sixty-day cubes made of Portland cement and broken-stone were crushed in an Olsen 200,000 pound machine; and the remaining cubes in a Riehle 100000-pound machine. The cubes were put into the machine in the same position as when moulded, i.e. top up, and carefully centered, no cushions being used. A cast-iron plate 8"×10½" was placed centrally on the cube and a pressure equalizer upon this. The descending top plate of the machine was then brought to a solid bearing and the pressure started.

The first effects of the pressure was a scaling off of the particles from the sides of the cube; and the first signs of failure were shown by vertical cracks on the surface.

The results of the several tests are given in Table II.

Table III shows the relative strength of the various concretes, and according to it, broken-stone makes a concrete 2.19 times as strong as gravel, and Portland cement a concrete 5.25 times as strong as natural cement.

Table IV shows the cost of the several grades of concrete. The quantities of the several ingredients required to produce a cubic yard of concrete in place were taken from Baker's Masonry Construction, page 1129. The prices used in the construction of this table are the average prices for which the materials can be secured at Champaign, Illinois, and are believed to be fairly representative.

Table V is a comparison of the strength and cost per cubic yard of different concretes, and also a comparison of the strength per $1.00 of cost per cubic yard.

Plate I presents the data for 30 days from Table V in graphical form. The results for 30 days is practically the mean of the three dates.

Plate II also presents part of the data for 30 days from Table V in graphical form, giving the strength per sq in. per $1 of cost per cu. yd. of concrete.

Conclusion.

By the use of Table V the engineer may select a concrete giving the greatest strength for the least money. However the same conclusion can be more easily obtained by inspecting Plate I. For example if a concrete is required giving a compressive strength of 750 lbs. per sq. in. Plate I shows that either of the two grades of concrete will satisfy the requirements, viz: that composed of Portland cement and broken-stone or that composed of Portland cement and gravel. The first will cost $3.12 per cu. yd. and the second $3.80; of course the cheaper is preferred. Plate I also shows that if a considerable strength is necessary a natural-cement concrete will not meet the requirements.

Plate II shows the relative economic value of various concretes; for example, the diagram shows that a concrete composed of Portland cement and gravel with 87% of the voids filled gives as great strength per $1.00 of cost per cu. yd. as a concrete composed of Portland cement and broken-stone having 30% of the voids filled.

Therefore when strength and cost are to be

considered it is immaterial which of the two concretes above is employed. However in this connection it should not be forgotten that the concrete having only 30% of the voids filled with mortar will be the more porous.

The author recognizes that in some particulars this investigation is less complete than is desirable, but it is all that could be accomplished in the time available.

Table II.

Crushing Strength of Concrete,

pounds per sq. in.

Ref. No.	Kind of Cement.	Kind of Aggregate.	Age when tested.		
			7 days.	30 days.	60 days.
1.	Portland	Bk. Stone.	1562	2062	3100
2.	"	"	1516	2012	2822
3.	"	"	1150	2003	2922
4.	"	"	1140	1958	2715
		Mean	1342	2009	2890
1.	"	Gravel.	604	937	1303
2.	"		555	828	1315
3.	"		565	879	1281
4.			531	895	1297
		Mean	566	885	1299
1.	Natural	Bk. Stone.	234	369	668
2.	"	"	203	390	581
3.	"	"	169	359	609
4.	"	"	219	384	647
		Mean	206	375	626
1.	"	Gravel	100	140	337
2	"	"	115	156	305
3.	"	"	130	197	309
4.	"	"	94	150	305
		Mean	107	161	314

Table III.

Relative Strengths of Different Concretes.

Ingredients used.	Ratio of Strength of	7 days	30 days	60 days	Mean.
Portland Cement	Bk. Stone to Gravel.	2.37	2.27	2.22	2.29
Natural Cement	"	1.93	2.33	2.00	2.09
Broken Stone	Port. Cement to Nat. Cement	6.52	5.36	4.62	5.50
Gravel	"	5.36	5.50	4.14	5.00

Table IV.

Cost of Different Concretes

Portland-Cement and Broken-Stone

0.94 bbl. Portland Cement @ $2.65	$2.49
0.93 cu. yds. unscreened broken stone @ $1.35	1.26
0.31 cu. yds sand @ $.60	.19
mixing and laying	.75
cost per cu. yd. in place	$4.69

Portland-Cement and Gravel

1.10 bbl. Portland Cement @ $2.65	$2.92
0.93 cu. yds. gravel @ $.60	.56
mixing and laying	.75
cost per cu. yd. in place	$4.23

Natural-Cement and Broken-Stone

1.07 bbl. Natural Cement @ $.60	$ .64
0.31 cu. yds. sand @ $.60	.19
0.93 cu. yds. unscreened broken stone @ $1.35	1.26
mixing and laying	.75
cost per cu. yd. in place	$2.84

Natural Cement and Gravel

1.23 bbl. Natural Cement @ $.60	$ .74
0.93 cu. yds. gravel @ $.60	.56
mixing and laying	.75
cost per cu. yd. in place	$2.05

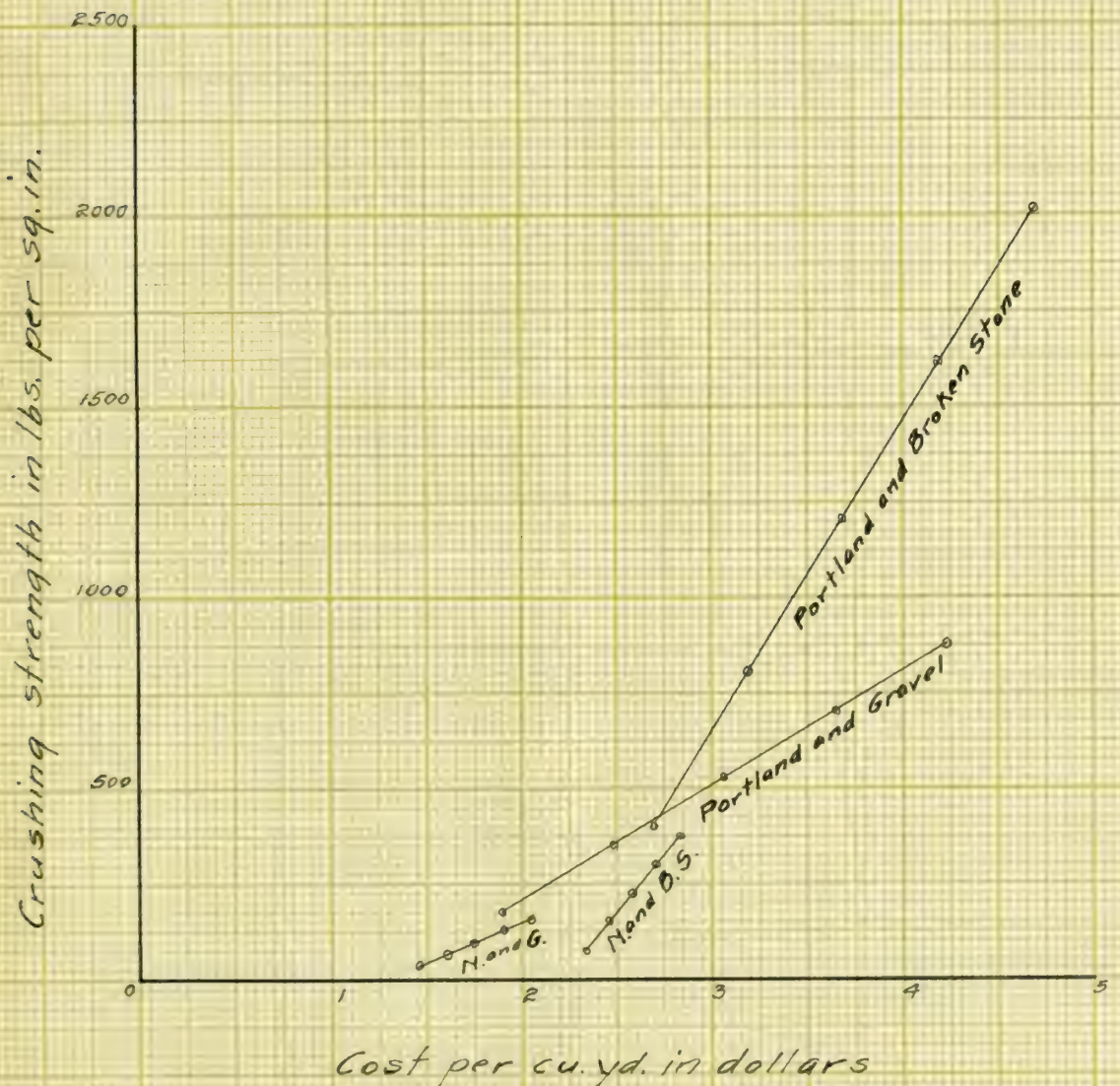
Table V.

Comparison of Cost and Strength of Different Concretes.

Kind of Concrete	Strength in lbs. per sq. in. per $1 of cost per cu. yd.														
	100% voids filled			80% voids filled			60% voids filled			40% voids filled			20% voids filled		
	Total Strength	Cost	Strength per $1	Total Strength	Cost	Strength per $1	Total Strength	Cost	Strength per $1	Total Strength	Cost	Strength per $1	Total Strength	Cost	Strength per $1
						7 day									
Port. and Bk. Stone	1342	$4.69	288	1074	$4.19	256	805	$3.69	218	538	$3.20	168	268	$2.70	100
Port. and Gravel	566	4.23	134	453	3.65	124	340	3.06	111	226	2.48	91	113	1.89	61
Nat. and Bk. Stone	206	2.84	73	165	2.71	61	124	2.57	48	82	2.46	34	41	2.33	18
Nat. and Gravel	107	2.05	53	86	1.90	45	64	1.75	37	43	1.61	27	21	1.46	15
						30 day									
Port. and Bk. Stone	2009	4.69	428	1607	4.19	385	1205	3.69	327	804	3.20	251	402	2.70	150
Port. and Gravel	885	4.23	209	708	3.65	194	531	3.06	174	354	2.48	143	177	1.89	99
Nat. and Bk. Stone	375	2.84	132	300	2.71	111	225	2.58	87	150	2.46	61	75	2.33	33
Nat. and Gravel	161	2.05	79	129	1.90	68	97	1.75	56	64	1.61	40	32	1.46	22
						60 day									
Port. and Bk. Stone	2890	4.69	616	2312	4.19	552	1734	3.69	470	1156	3.20	361	578	2.70	214
Port. and Gravel	1299	4.23	307	1040	3.65	285	780	3.06	255	520	2.48	210	260	1.89	138
Nat. and Bk. Stone	626	2.84	221	501	2.71	185	376	2.58	146	250	2.46	102	125	2.33	54
Nat. and Gravel	314	2.05	154	251	1.90	134	188	1.75	107	126	1.61	79	63	1.46	44

Plate I

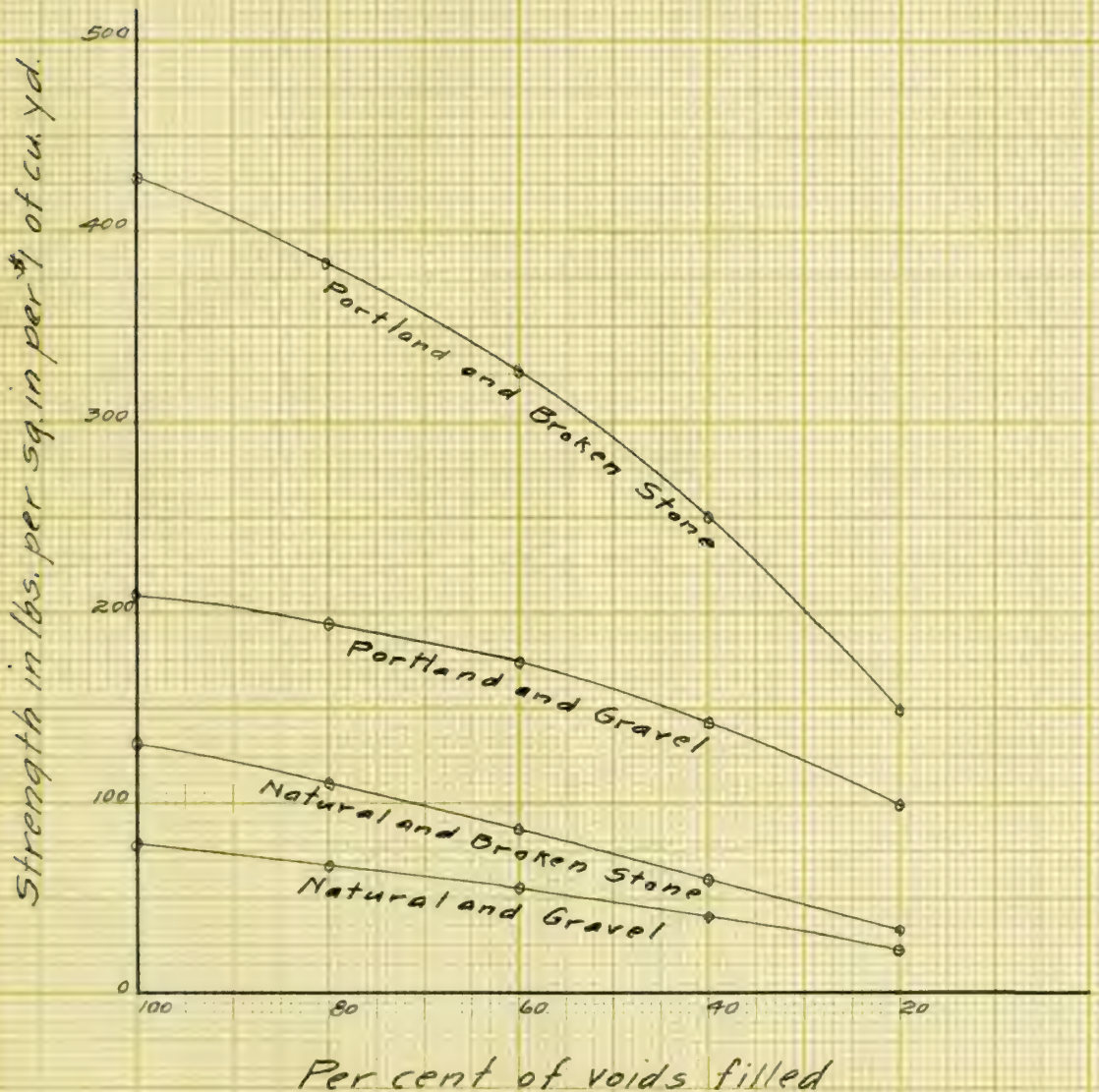
Data Showing Relation between Strength and Cost of Concrete.



EUGENE DIETZGEN CO., CHICAGO.

Plate II.

Data Showing Strength of Various Concrete, per $1 of Cost per Cubic Yard.



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